Effect of melt temperature, cleanout cycle, continuous casting direction (horizontal/vertical) and super-cooler size on tensile strength, elongation percentage and microstructure of continuous cast copper alloys

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Effect of Melt Temperature, Cleanout Cycle, Continuous Casting Direction (Horizontal / Vertical) and Super-Cooler Size on Tensile Strength, Elongation Percentage and Microstructure of Continuous Cast Copper Alloy

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Abstract

The main processing factors that control the solidification of castings, and consequently, microstructure and mechanical properties, are: chemical composition, liquid metal treatment, cooling rate and temperature gradient. In this work, the influence of melt temperature; cleanout cycle, continuous casting direction (horizontal / vertical) and super-cooler size on tensile strength and elongation percentage of continuous cast copper alloys has been characterized by tensile machine and confirmed by microstructure examination. A significant difference on tensile strength and elongation percentage has been observed by changing the processing parameters. By optimizing these parameters, the mechanical properties of continuous copper alloys can be substantially improved. As a particular example, super cooler size could improve the elongation of samples from 38% to 45% or cleanout cycle could improve the tensile strength of samples from 532 MPa to 561 MPa.

1. Introduction

Copper and copper alloys are ranked third behind iron and steel materials as well as aluminium alloys in industry. Copper is one of the oldest known metals, which can be used in various ranges of applications such as electronic devices, electrical wiring, cables, refrigeration tubing and plumbing, due to the beneficial characteristics such as excellent heat conductivity and electrical conductivity, good corrosion resistance and good machinability [1,2]. Globally, the continuous casting process produces one million tons of copper metals each year [3].

The continuous casting process is a technology, which is used in manufacturing industry to cast a continuous length of metal. This technique is frequently used in steel, aluminium, copper and other alloys industrial applications to produce a wide range of different profiles such as wire rod, tube shell, billet and strip. The use of continuous casting gives a range of advantages in comparison to the thermo-mechanical process [4].

The main advantage of the continuous casting is lower cost and high production flexibility. Lower cost of operation for larger runs make this method very economical. However, continuous casting has some limitations that have kept it from becoming a more widely used technology, such as low ductility [5,6].

Grain refinement is the mechanism that improves the strength and ductility of materials. The grain refining process development program began in 1975 to produce a fine, equiaxed grain structure with a vacuum-cast IN713LC radial turbine wheel [7]. Since 1980s, various grain-refining techniques have been developed and this research is still on going. Currently, the grain refining methods are mainly classified into three categories i.e., (a) thermal by cooling rate control, (b) chemical by adding the nucleant agents addition into the melt and (c) dynamical by mechanical agitation [8].

In the chemical grain refining process, the amount of refiner, difference in density between matrix and refiner, lack of uniform dispersion of nucleant agents, poor wettability or in-compatibility between metal and refiner particles are the main limitation issues to deal with [9,10]. Although an improvement of ductility can be obtained by mechanical techniques but the problem of this mechanical way is expensive [11].

In comparison to chemical and mechanical technique, refine grain size by thermal mean has substantial cost benefits. This research focuses on thermal technique to optimize the performance of continuous casting copper alloys. The aim of this paper is to investigate the impact melt temperature; cleanout cycle, continuous casting types (horizontal / vertical) and super-cooler size on mechanical properties of continuous cast copper and copper alloys.

2. Materials for Research

The material preparation, set-up, casting procedure, casting parameters and tensile test analysis are explained from section 2.1 to 2.4.

2.1 Material Preparation

Copper cathode is used as the raw material input to produce copper rod in 8-22 mm diameter. The copper cathode feedstocks were melted in Rautomead RS (commercial name) continuous casting machine. Mass spectrometry was used (model: AMETEK) as an analytical technique to determine the chemical composition of metallic samples.

2.2 Set-up

This work was performed at Rautomead's premises in Dundee, UK and using Rautomead RS continuous casting machine. The main tool used by Rautomead in these trials was the adaption of different casting parameters to achieve the better mechanical properties. A standard Rautomead horizontal continuous casting parameters and withdrawal system set-up for 8 - 22 mm rod was used, which consisted of pull distance, push distance, pull dwell, acceleration and deceleration, casting speed and water flow rate.

2.3 Continuous Casting Procedure

Rautomead casting line is generally used for producing wire rod, tube shell, strip and billet. Continuous casting is a process of melting and continuous solidification. As shown in Figure 1, continuous casting consists of graphite heating element, heated furnace with graphite crucible furnace and holding furnace, together with graphite die and super cooler assembly with withdrawal mechanism controlled by PLC based servo motor.

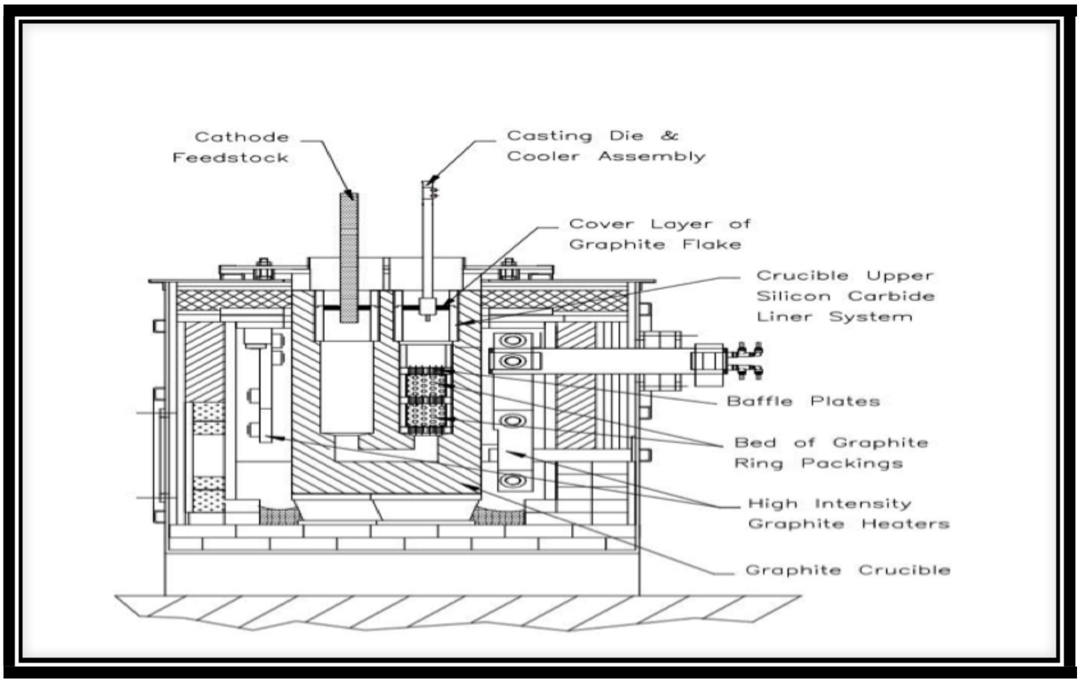


Fig 1. Section through Rautomead RS Upwards Vertical Continuous Casting Furnace

2.3.1 Super-cooler:

Super-cooler is the most important parts of continuous casting machine and it is mounted on top of the holding crucible. The super cooler is cooled by re-circulation of water. During the continuous casting the molten metal enters the die and solidifies in the shape of die bore. Fig 2 shows the schematic of super-cooler assembly.

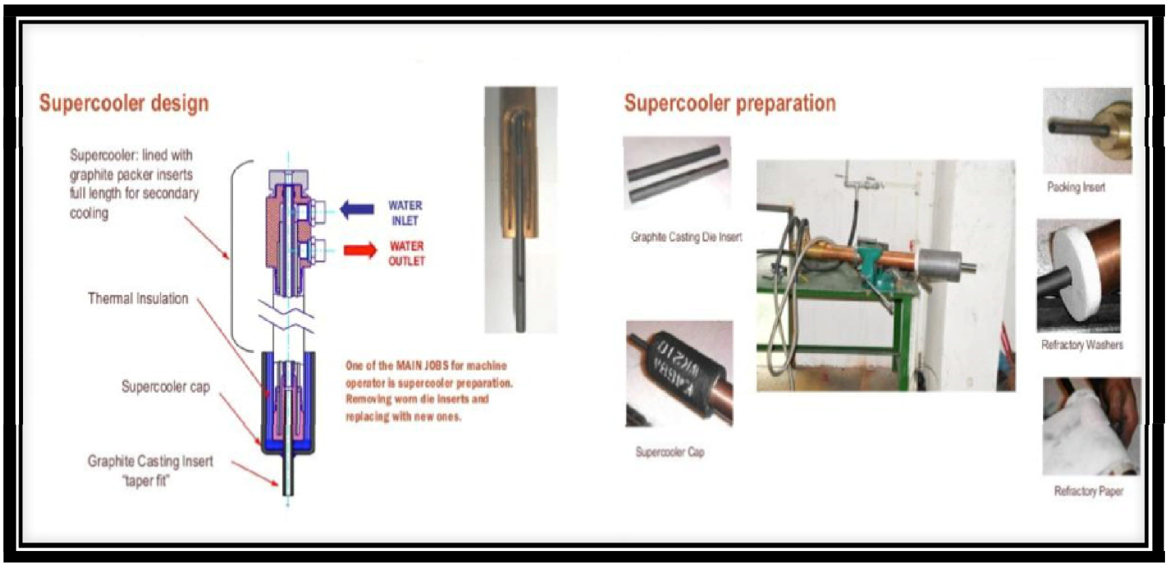


Fig 2. Super-cooler assembly

2.3.2 RS withdrawal System

As shown in Figure 3, in both vertical and horizontal continuous casting process generally four different withdrawal cycles are used including: [12].

1. Non-intermittent extraction which is usually used for casting alloys with low temperature interval of solidification such as pure metals or casting at high cooling rate
2. Intermittent extraction with a pause, which is used for casting of copper alloys at lower cooling rates.
3. Intermittent extraction with one pushback, which usually used for the kind of alloys having wide temperature interval of solidification.
4. Intermittent extraction with two pushback, which is used for casting alloys containing constituents penetrating into the graphite pores and causing sticking the casting to the graphite surface.

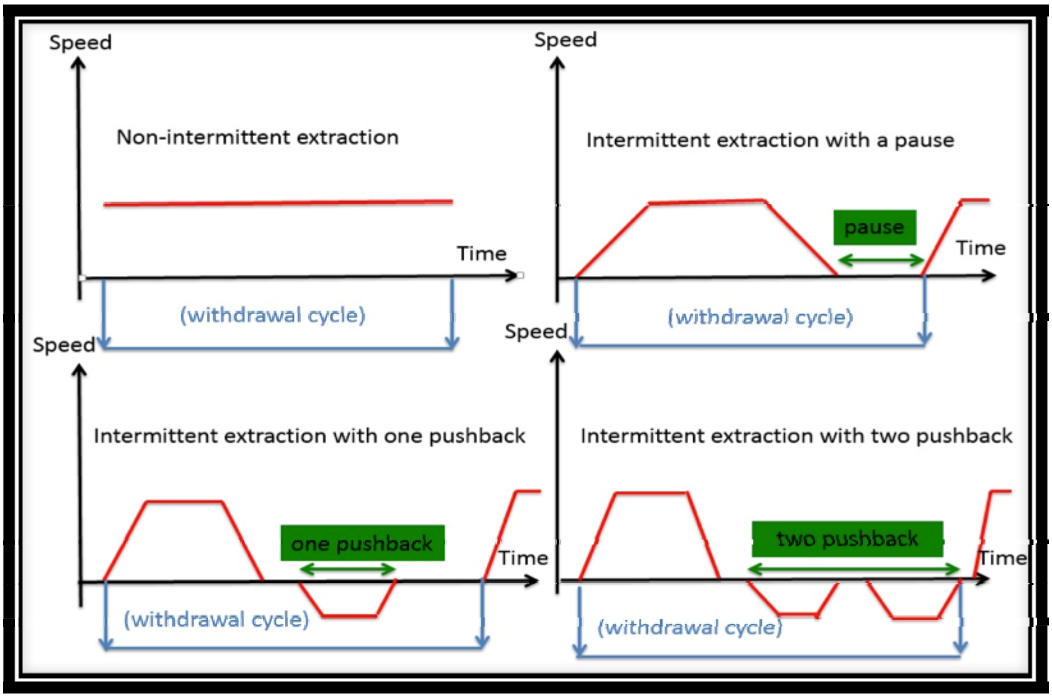


Fig 3. Withdrawal cycles

2.3.3 RS casting parameters

The continuous casting process is controlled automatically but the quality and productivity of resulting product are dependent on the casting parameters used during the casting process such as:

- Melt temperature
- Withdrawal system
- Continuous casting direction
- Super cooler size
- Cooling water flow rate
- Casting speed
- Pull distance
- Casting die material

Both withdrawal cycle and casting parameters for each application were used. Proper withdrawal cycle and casting parameters selection is critical to the ultimate success of the continuous casting process. This paper will discuss the effect of melt temperature, withdrawal system, continuous casting direction and super cooler size on tensile strength and elongation of continuous cast copper alloys.

2.4 Tensile Testing

In order to evaluate the mechanical properties of all samples tested throughout this work, the uniaxial tensile test is used. The test specimens were prepared according to ASTM E8 / E8M - 13a (Standard Test Methods for Tension Testing of Metallic Materials) and for each cast, three samples were selected and an average was taken. The tension test was then accomplished by gripping opposite ends of the test specimens within the load frame of a test machine. The tensile test applied a uniaxial force to the samples to measure the strength and ductility in a given direction. Experimental tests were carried out at the materials and structures testing laboratory at University of Dundee. The tensile test was performed using a universal Instron machine (Model—4204) to investigate the tensile strength (MPa) of the material, as well as to find the ductility in terms of the elongation percentage of the alloy. From the measured data, the tensile strength is calculated by dividing the maximum load by the original cross-sectional area of the test specimen and the percentage elongation of each sample is calculated through the following formula,

$$e, \% = [(\text{final gauge length} - \text{original gauge length}) / \text{original gauge length}] \times 100$$

Ductility is measured by determining the percent reduction of area on a specimen during a tensile test. Test done as following steps:

1. Before starting of tensile test, suitable grip selected. In case of choosing the incorrect set up, specimen may slip or even break inside the gripped area and this would lead to invalid results.
2. Enter data into the computer, which is connected to the machine.
3. Put the specimen in grip.
4. Make sure that the specimen is holed by both grips up and down.
5. Testing is allowed to run at a suitable speed for the entire test.
6. The force is applied till fracture of specimens.

2.5 Metallography

Samples for microstructural observations were cut with a clean sharp hacksaw. Sectioning of the test sample was performed carefully to avoid destroying the structure of the material. After the sample is sectioned to a convenient size, samples were then ground by using coarse abrasive paper (Grade No 60) and subsequently wet & dry fine silicon carbide paper (Grit No 2500) SiC papers and polished on a cloth with a diamond suspension and lubricating solution, beginning with 6 micron and then subsequently using 3, 1 and ¼ micron. The polished samples were etched according to the ASTM E407-07 (Standard Practice for Micro-Etching Metals and Alloys), in a solution of Nitric acid and distilled water.

3. Experiment

3.1 Melt Temperature

Melt superheating treatment is an effective method of refinement grain [13]. In the past decades, the effects of melt superheating on aluminium and Magnesium alloy have been studied [14, 15].
In the present paper an experimental investigation on continuous casting of Oxygen Free Copper (OFCu) has been conducted. The main objectives of the research were to investigate the influence of casting temperature in the range of 1140°C to 1097°C on the tensile strength and elongation percentage in continuous cast oxygen free copper (OFCu) from high-purity copper cathode (LME grade A) to obtain the optimum treatment temperature.
The trials were carried out on the model RS080 vertically upwards-continuous casting machine. Pouring was done with four different temperatures at 1140°C, 1120°C, 1100°C and 1097°C. For all samples, we have utilized a standard Rautomead set-up for 8 mm rod, which consisted of an overall speed of 4.3 m/min (71.67 mm/sec). Then tensile strength and elongation percentage of continuous cast was investigated by the universal tensile machine. Three samples are selected and an average taken. Table 1 gives the copper samples tested in this study.

Table 1. OFCu samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (Sec)	Acceleration (Sec)	Deceleration (Sec)	Casting Speed (mm/min)	Water Flow Rate (ltrs/min)	Melt Temperature (°C)
Cast 1	8	Graphite	0.5	0	0.002	0.002	4300	45	1097 (°C)
Cast 2	8	Graphite	0.5	0	0.002	0.002	4300	45	1100 (°C)
Cast 3	8	Graphite	0.5	0	0.002	0.002	4300	45	1120 (°C)
Cast 4	8	Graphite	0.5	0	0.002	0.002	4300	45	1140 (°C)

3.2 Cleanout Cycles

The aim of this section was to understand the relationships between cleanout cycle and mechanical properties of continuous cast copper alloy. The cleanout cycle is a specified drawing process during the casting process, the drawing speed changes periodically which can be used when casting specific copper alloys, for example Aluminum Bronze.
The way the cleanout cycle works is that after the rod has been casting at the run speed for a specified run time, the speed then ramps down over a specified ramp down time to a specified cleanout speed. The output of the rod then remains at this lower cleanout speed for a specified cleanout time before it starts ramping back up again over a specified ramp up time back to the original run speed. It will then remain at the run speed until the run time has elapsed again making the cleanout cycle start again. Figure 4 shows the cleanout cycle graph. For the cleanout cycle to work the cleanout speed is normally lower than the Run speed.
The run time, ramp down time, cleanout speed and time and ramp up time can be selected and altered on the machine control touch screens. Setting the run time value to zero will turn the cleanout cycle off. Changes to the cleanout operating values on the touch screen whilst casting should only be done by an experienced operator and may result in rod breakages or defects.

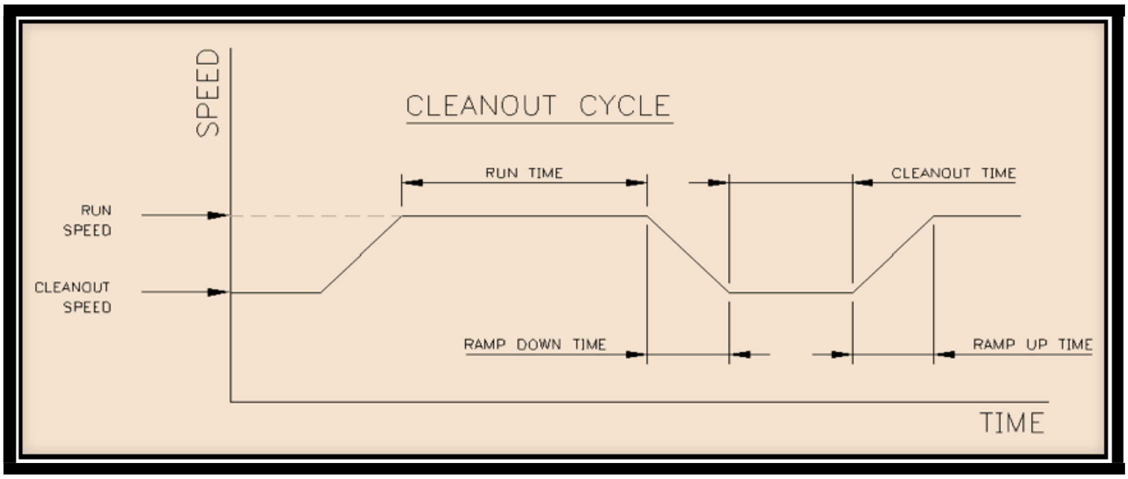


Figure 4. The cleanout cycle

Aluminium bronze is a type of bronze in which aluminium is the main alloying metal added to copper, in contrast to standard bronze (copper and tin) or brass (copper and zinc). A variety of aluminium bronzes of differing compositions have found industrial use, with most ranging from 5% to 11% aluminium by weight, the remaining mass being copper; other alloying agents such as iron, nickel, manganese, and silicon are also sometimes added to aluminium bronzes. Aluminum bronze is the highest strength standard copper based alloy.
In this study, experimental work to produce 10 mm diameter aluminium-bronze rod (Cu-AL10%-Fe1%) were performed using RS80 vertically upward casting machine to evaluate the effect of cleanout cycle on tensile strength and elongation percentage of aluminium-bronze alloys. Then a tensile test at room temperature was carried out according to ASTM standard. The test specimens were prepared according to ASTM standard. From the measured result and data, the percentage elongation of each sample as well as ultimate tensile strength was calculated. Table 2 shows the samples tested in this report.

Table 2. Aluminum Bronze samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (Sec)	Acceleration (Sec)	Deceleration (Sec)	Casting Speed (mm/min)	Water Flow Rate (ltrs/min)	Cleanout Cycle
Cast 1	10	Graphite	8	0	0.04	0.04	300	30	No
Cast 2	10	Graphite	8	0	0.04	0.04	1450	30	Yes

3.3 Continuous Casting Direction (Horizontal/Vertical)

The most common continuous casting methods are horizontal and vertical. The selection of continuous casting types is depends on the various parameters such as productivity rate, the materials, form, shape and dimension of the final product. One of the purposes of this work was to experimentally investigate the dependency of the continuous casting types and mechanical properties of continuous cast copper alloys. The cast trial was attempted using a standard upward and horizontal continuous casting machine. The alloy was 2% Ag balance Cu. The trial produced 12.5mm diameter samples vertically and then horizontally. Alloy contents are summarised in Table 3. In this study, two batches of samples were cast using different continuous casting types. Then to investigate the casting type's effect on the mechanical properties of CuAg alloy, a tensile test at room temperature was carried out according to ASTM standard. To evaluate the mechanical properties of Cast1 and Cast2, the tensile test was performed to investigate the tensile strength (MPa) of the material as well as to find the ductility in terms of elongation percentage of the alloy. The test specimens were prepared according to ASTM standard. The specimens were tested using a computerised universal testing machine (Make: Instron; Model: 4204). Three samples are selected and an average taken.

Table 3. CuAg samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (Sec)	Acceleration (Sec)	Deceleration (Sec)	Casting Speed (mm/min)	Water Flow Rate (ltrs/min)	Casting Type
Cast 1	12.5	Graphite	5	0.1	0.002	0.002	300	50	Horizontal
Cast 2	12.5	Graphite	5	0.1	0.002	0.002	300	50	Vertical

3.4 Super-cooler Size

Solidification and cooling control are key important factors of the continuous casting process. In continuous casting process, as shown in Figure 2, at the top of crucible a die and cooler device (known as a super-cooler assembly with graphite die) is fixed vertically keeping the die immersed in molten metal. The super cooler is cooled by re-circulation of water. The molten metal enters the die & gets solidified in the shape of die bore. Super-cooler in continuous casting plays a key role in transforming heat from the mould and solidifying metal during the continuous casting of copper alloys. [16]. In order to evaluate the quality of continuous casting of copper alloys it is necessary to have a detailed knowledge of efficiency of super-cooler size on mechanical properties of continuous cast copper alloys. This work was performed using a variety of sizes of super-coolers. Two different super-cooler size (76 mm and 48 mm) have been studied in this research. The alloy was 0.18% Mg balance Cu. The trial produced a vertically upward cast 15 mm diameter sample coil. Tensile strength and elongation percentage of continuous cast was investigated by universal tensile machine. Three samples were selected and an average was taken. Table 4 provided information on the copper samples tested in this study.

Table 4. CuMg samples tested in this research

Sample	Rod dia (mm)	Die	Pull Distance (mm)	Pull Dwell (Sec)	Acceleration (Sec)	Deceleration (Sec)	Casting Speed (mm/min)	Water Flow Rate (ltrs/min)	Super-Cooler Size
Cast 1	15	Graphite	6	0.1	0.002	0.002	800	45	76mm
Cast 2	15	Graphite	6	0.1	0.002	0.002	800	45	48mm

4. Results and Discussion

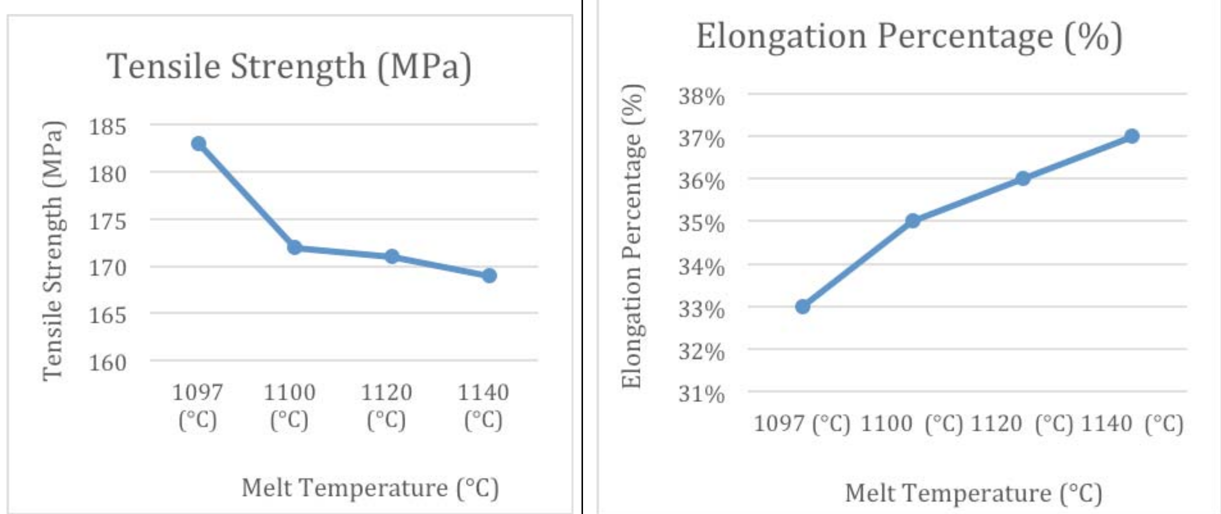
4.1 Melt Temperature

The objective of this study was to find the effect of melt temperature on the mechanical properties of continuous cast copper rod by varying melt temperature.

After experiments the tensile strength has been examined and it was found that strength of oxygen free continuous cast copper (OFCu) has changed when changing the melt temperature. It can be seen that the tensile strength drops to 169.56 MPa from 183.14 when the melt temperature is increased from 1097 ºC to 1140 ºC. The results of average elongation percentage and tensile strength of copper alloy samples are presented in Fig. 5, Fig. 6 and Table 5. It can be seen that samples in Cast 4 has the higher elongation percentage and lower tensile strength.
Elongation of these samples are increased by 33%, 35%, 36% and 37% respectively, when the melt temperature is increased from 1097 to 1140 °C. In summary, the mechanical properties of continuous cast oxygen free copper (OFCu) can be changed by increasing the melt temperature. The reason is because the melt temperature is one of the most important factors affecting the size of atomic clusters, as the temperature changes can influence the nucleation. In the other side, according to the relationship between the grain growth rate and degree of super-cooling, the larger the degree of super-cooling is the faster grain growth rate. So, with the increase of degree of super-cooling the grain size is decreased which then results in increasing elongation percentage [17, 18].

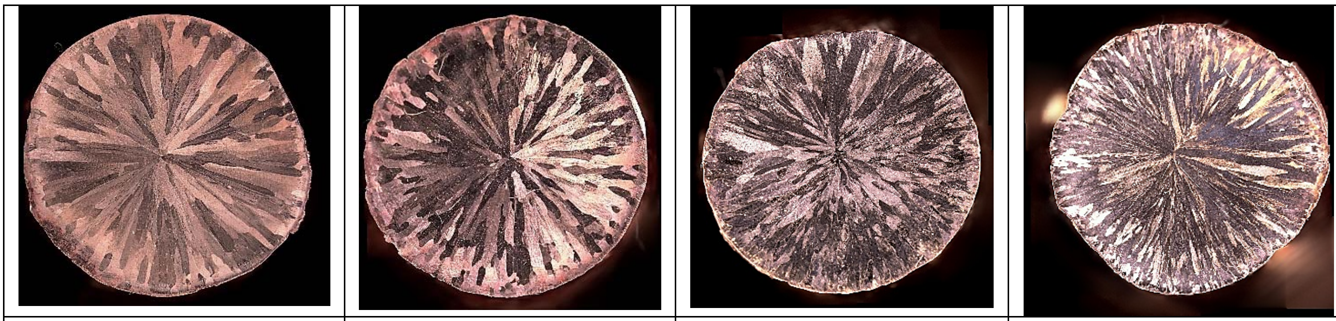
Table 5. Tensile strength and elongation percentage of OFCu samples

Sample name	Melt Temperature (°C)	Tensile Strength (MPa)	Elongation Percentage (%)
Cast 1	1097 (°C)	183	33%
Cast 2	1100 (°C)	172	35%
Cast 3	1120 (°C)	171	36%
Cast 4	1140 (°C)	169	37%



Tensile Strength (MPa)	Elongation Percentage (%)

Fig. 5. Tensile strength and elongation percentage of OFCu samples



1097(°C)	1100(°C)	1120(°C)	1140(°C)

Fig. 6. Comparison grain structure of OFCu samples

4.2 Cleanout Cycles

Table 6 shows the results obtained from the tensile test carried out on Cast 1 and Cast 2. The comparison graph is also summarised in Fig. 7. The results showed that ultimate tensile strength (UTS) of Cast 2 is higher than Cast 1, and that the adoption of a cleanout cycle can improve the tensile strength of aluminium bronze samples from 532 MPa to 561 MPa. It could also be observed that the value of elongation percentage of Cast 2 is higher than Cast 1.

When casting some copper alloys which contain certain low melting point elements, such as tin or zinc, or casting specific copper alloys like aluminium bronze, a "build up" of the these elements can occur on the inside surface of the casting die where solidification is taking place which can lead to rod surface defects and breakages if left unchecked by slowly blocking the die. The Rautomead RS – series withdrawal unit drives are fitted with cleanout cycle option designed to overcome this "build up" problem. Cleanout cycle operate in a cycle manner during the casting process and are designed such that, as the rod is being slowed down, so the solidification point of the metal being cast in the die moves towards the hot end of the die. The "build up" in the die is then attached to the solidified rod and is removed when the casting speed returns to the normal "run speed" leaving a clean die surface. Cleanout cycle gives a slightly increase in the elongation percentage from 32% to 35%. The reason is that the cleanout cycle can help to remove deposits, which may build up on the bore of casting die in the vicinity of the solidification zone. The casting speed is ramped up and down on the continuous loop. This has the effect of moving the solidification zone up and down the casting die. The other reason is oscillation mark.

In continuous casting processes, to reduce friction and avoid sticking and breakout of the liquid metal during casting, mould oscillation is required. This oscillation is well-known to cause surface defects of continuous cast alloys i.e oscillation mark as shown in Figure 8 [19, 20].

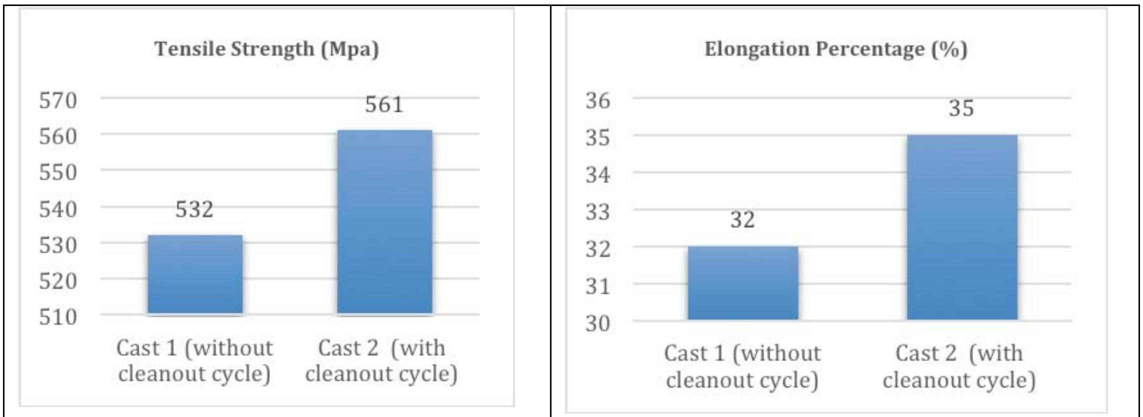
When the liquid metal inside the casting die starts to solidify and during the solidification, surface defects called oscillation marks are formed. The oscillation marks appears as grooves perpendicular to the casting direction [21]. And it may cause cracking and enhance the mechanical properties and yield [22].

Depth of crack, width of crack and shape of crack are three main parameters that use in order to describe the crack behavior. There is a correlation between oscillation mark depth and width, as deeper marks generally have a tendency to be wider [23, 24]. U and V shaped cracks on the surface are two main categories of oscillation marks and V shape crack is much worse compared to U shape [25].

To ensure the acceptability of surface finish of continuously cast aluminum bronze alloy, the depth, width and shape of the cracks must be evaluated. In this work, we have established a technique to display and measure the size, depth and width of surface cracks in continuously cast rod, which will be hereby, referred to as the “crack depth analysis”. In order to measure depth and width of surface crack of AlBronze samples, the samples were cut longitudinally perpendicular to the oscillation mark and then mounted by hot mount press in epoxy resin. The longitudinal section was machined flat, ground and polished respectively. In this work, all samples were ground first using alumina grinding paper coarse abrasive paper and subsequently wet & dry fine silicon carbide paper. Then the samples were polished using diamond paste until the grinding scratches were removed. After polishing, the samples were cleaned by acetone in an ultrasonic cleaner and then dried with nitrogen gas. The depth and width of oscillation mark was examined and photographed using a digital microscope. This process was conducted by using KEYENCE digital optical microscope which is facilitated with an image capturing facility to save the images into hard-drive as JPEG files. To view the oscillation marks, which are in the orders of micrometers (μm), KEYENCE digital microscope- Model VHX-1000E was the most important instruments used in this research as analytical tools.
In theory; temperature, strain rate and state of stress are most factors affecting fracture and cracks play the most important role in fracture. Crack position, crack length, crack width and crack orientation are recognized as a crack characterization.
Results of the rod surface crack length, width and shape are presented in Figure 9 and 10. The results show that surface defects are presented in cast 1 which was without cleanout, mainly in V-shapes cracks and cast 2, which was with cleanout, mainly in U-shapes cracks. According to the fracture theory, the fracture and crack growth is strongly dependent on the crack size. V-shapes cracks in cast 1 can join each other faster compare to the U-shapes cracks in cast 2. So the tensile strength and elongation percentage of cast 2 is better than cast 1.

Table 6. Tensile strength and elongation percentage of Aluminium Bronze samples

Sample name	Cleanout Cycle	Tensile Strength (MPa)	Elongation Percentage (%)
Cast 1	No	532	32
Cast 2	Yes	561	35



Tensile strength	Elongation percentage

Fig. 7. Tensile strength and elongation percentage of Aluminum Bronze samples

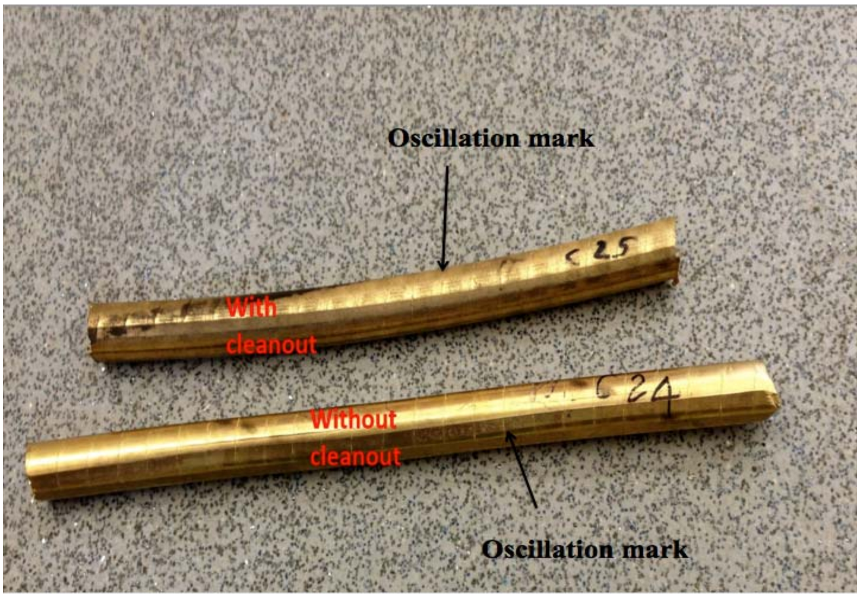
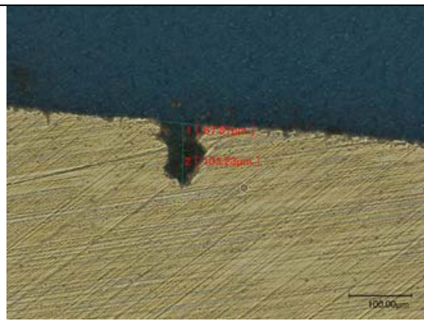
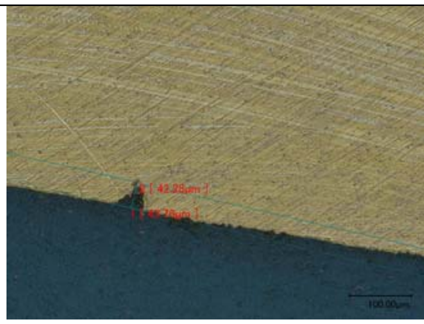


Fig. 8. Aluminum Bronze samples

Sample	Crack position	Depth (µm)	Width (µm)	Shape	Image
Without cleanout	Top	103.23	87.81	Sharp (V shape)	
Without cleanout	Bottom	42.28	49.76	Sharp (V shape)	

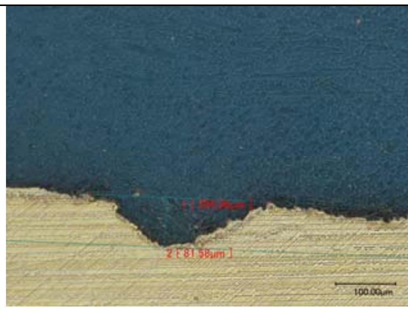
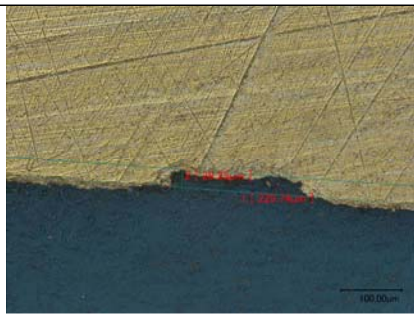
With cleanout	Top	81.58	296.96	Dull (U shape)	
With cleanout	Bottom	29.25	229.74	Dull (U shape)	

Fig. 9. Crack depth analysis

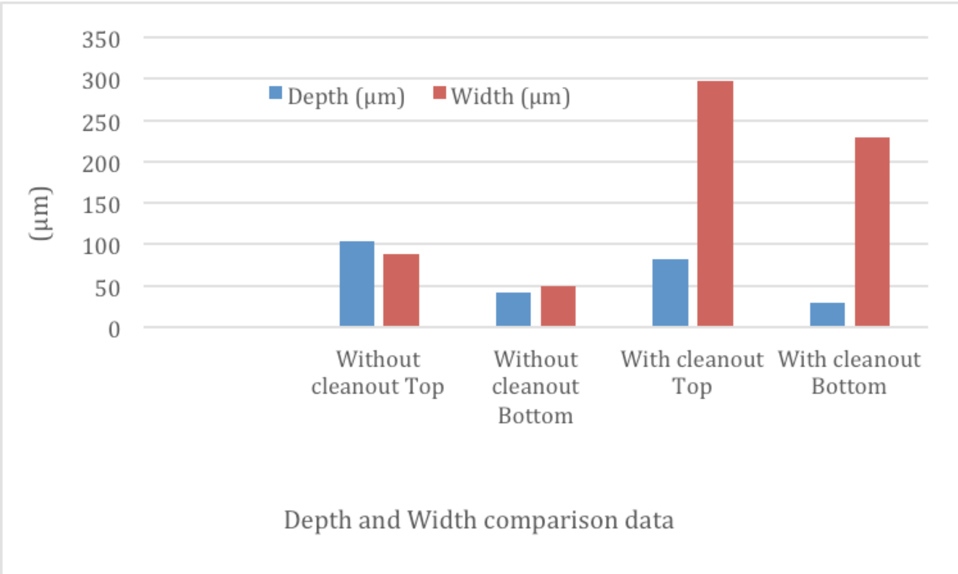


Fig. 10. Crack depth analysis

4.3 Continuous Casting Types (Horizontal / Vertical)

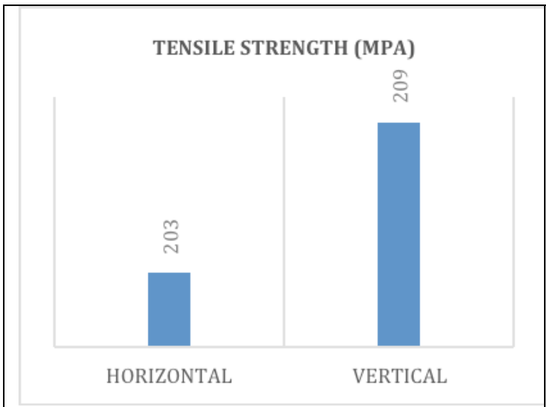
The objective of this study was to find the effect of continuous casting types on tensile strength and elongation percentage of continuous cast cooper rod and to identify that, the vertical or horizontal continuous casting methods has better efficiency on mechanical properties of cooper alloy.

According to the authors experiment, horizontal continuous casting method has substantial cost benefits over the vertical continuous casting. This technique required lower capital investment, easier installation and is more convenient technique for operator. However, the preferred casting technique is determined by the alloy and by

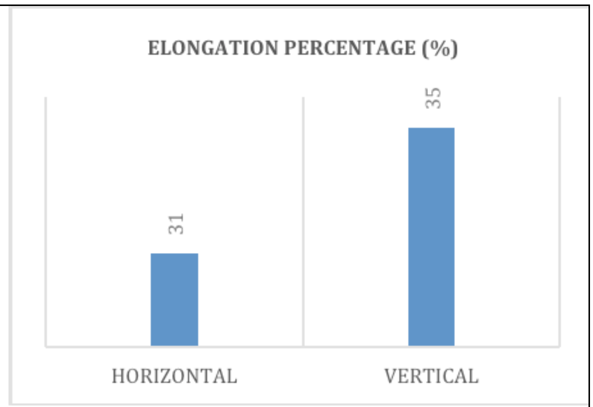
the size range being produced. In order to understand this aspect, this trial produced 12.5mm diameter Cu2%Ag samples vertically and then horizontally and then the samples were evaluated with a universal tensile machine for measuring the tensile strength and elongation percentage. The influence of casting types on the tensile strength and elongation percentage of Cu2%Ag is shown in Table 7 and Figures 11,12 and 13.
Highest UTS value is for cast 2 which cast vertically and lowest value of UTS is for cast 1 which produced horizontally. As can be seen in the following table and figures, the average elongation percentage of sample cast 2 is higher than cast 1.
In vertical continuous casting, the molten metal flows into a water-cooled die, which is held within the crucible, and solidification of the alloy occurs. During horizontal continuous casting, metal flows from the front of the crucible and into a water-cooled die where solidification takes place. With precise control of temperature the smaller grain structures are created. Smaller grains have greater ratios of surface area to volume, which means a bigger ratio of grain boundaries to dislocations. The more grain boundaries that occur, the higher strength.
There is a slight different between the grain structure because the gravity plays a part and changing the grain structure. The bottom in horizontal casting is usually is better cooled and has a finer grain.

Table 7. Tensile strength and elongation percentage of CuAg samples

Sample name	Casting Type	Tensile Strength (MPa)	Elongation Percentage (%)
Cast 1	Horizontal	203	31
Cast 2	Vertical	209	35



Tensile strength



Elongation percentage

Fig. 11. Tensile strength and elongation percentage of CuAg samples

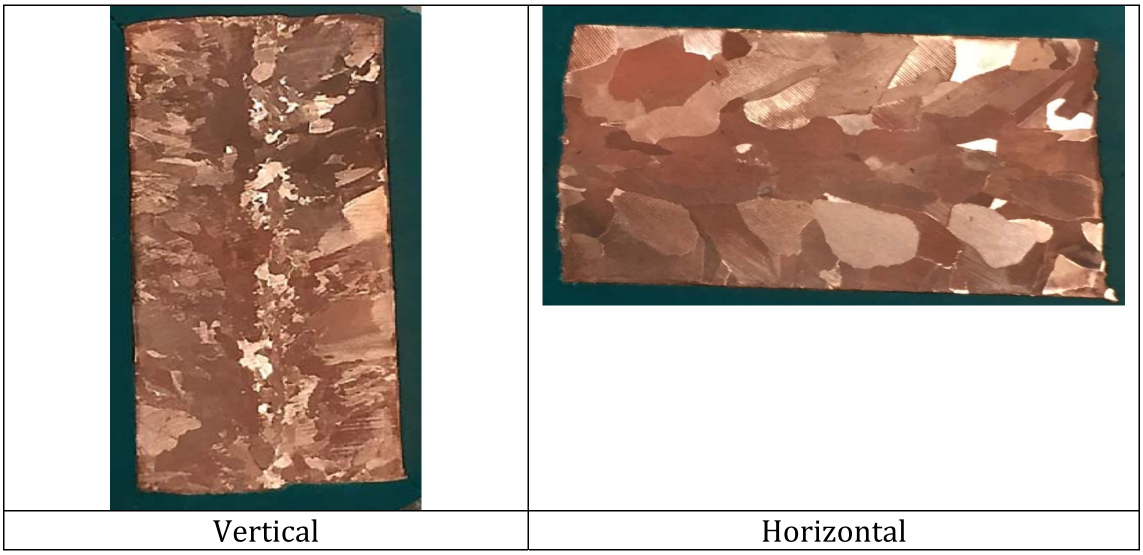


Fig.12 Comparison grain structure of CuAg samples (Longitudinal section)

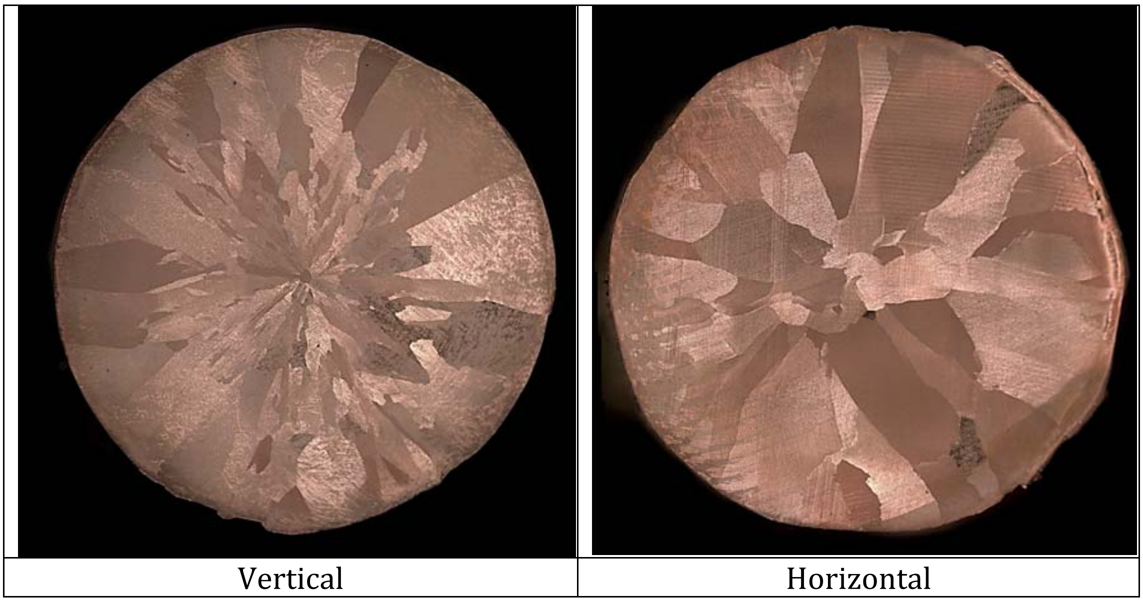


Fig.13 Comparison grain structure of CuAg samples (Cross section)

4.4 Super-cooler size

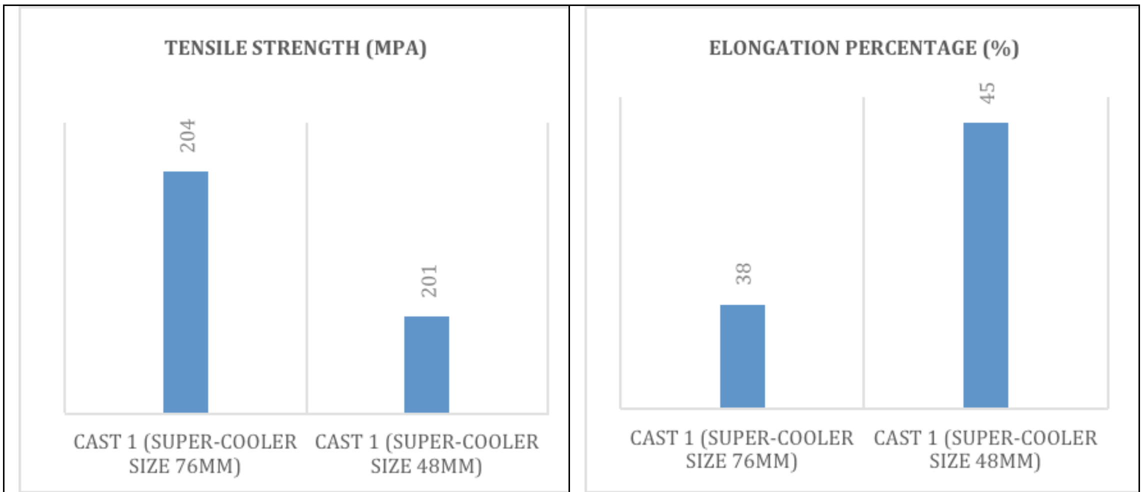
Results of the mechanical tests are presented in Table 8.The Figures 14 and 15 shows the effect of super-cooler size on the tensile strength and elongation percentage of continuous cast copper alloys. It can be noticed that the decrease of super-cooler size from 76mm to 48mm gives a slightly increase in the elongation percentage from 38% to 45% and decrease tensile strength from 204 MPa to 201 MPa. This is due to the differences between die walls of each super-cooler type. 48mm super-coolers have thinner die walls compares to 76mm super-cooler. This leads to different cooling rate. Cooling is slower in thicker die walls compared to thinner.

Solidification of alloys in continuous casting process is controlled by its cooling system. Cooling rate will affect the microstrucutre and is turn the mechanical properties of the materials.

Slow cooling will reduce the transformation temperatures as if molten copper is cooled slowly, grains have a longer time to grow. Thus, a large grain size is formed. Therefore, faster cooling rate will provide a harder material whereas slower cooling rate will make the softer material. Apart of this, during the slow cooling of casting CuMg alloy, the precipitated magnesium that formed in copper matrix is coarse. Also, when the cooling rate is slow, some of the large clusters of atoms in the liquid develop interfaces and become the nuclei for the solid grains that are to form. During solidification the first nuclei increase in size as more and more atoms transfer from the liquid state to the growing solid. Eventually all the liquid transforms and large grains develop. The grain boundaries represent the meeting points of growth from the various nuclei initially formed. When the cooling rate is fast, many more clusters develop and each grows rapidly until it meets its neighbour. As a result more grains form and the grain size in the solid metal is finer [26, 27].

Table 8. Tensile strength and elongation percentage of CuMg samples

Sample name	Super-Cooler Size	Tensile Strength (MPa)	Elongation Percentage (%)
Cast 1	76mm	204	38
Cast 2	48mm	201	45



Tensile strength	Elongation percentage

Fig. 14. Tensile strength and elongation percentage of CuMg samples

76mm	48mm

Fig.15 Comparison grain structure of CuMg samples

4. Conclusions and Future Work

The effects of melt temperature; cleanout cycling, continuous casting direction (horizontal / vertical) and super-cooler size on the mechanical and physical properties of continuous cast copper alloys were investigated using tensile machine and metallography examination. From the above experimental results, some important conclusions can be drawn:

1. Results showed that according to the relationship between the grain growth rate and degree of super-cooling, when melt temperature was increased a reduction of grain size and an improvement of elongation percentage was observed. However, tensile strength of the alloy decreases with an increase of melt temperature.
2. Cleanout cycle can help to remove deposits, which may build up on the bore of casting die in the vicinity of the solidification zone. The use of a cleanout cycle strongly affects the mechanical properties of continuous cast copper. Both elongation percentage and tensile strength improved when a cleanout cycle used.
3. Super-cooler size can enhance on the both physical and mechanical properties of continuous cast copper.
4. Changing continuous casting type from horizontal to vertical can improve the mechanical properties of continuous cast copper. This is due to controlling the cooling rate and changing the grain structure.
5. A limitation observed in this study is that if melt temperature is increased (for example, above 1140C), this would result in change in as-cast quality as well as potentially rod fracture. Thus at very high melt temperature, changing parameters should be avoided.
6. As for future work, this research can be extended by comparing the influence of other casting parameters on tensile strength and elongation percentage of continuous cast copper alloy such as material changes in casting die inserts.

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